

Group III Nitride VCSEL Structure grown by MBE and Ordering in AlGaN Alloys

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Acknowledgments

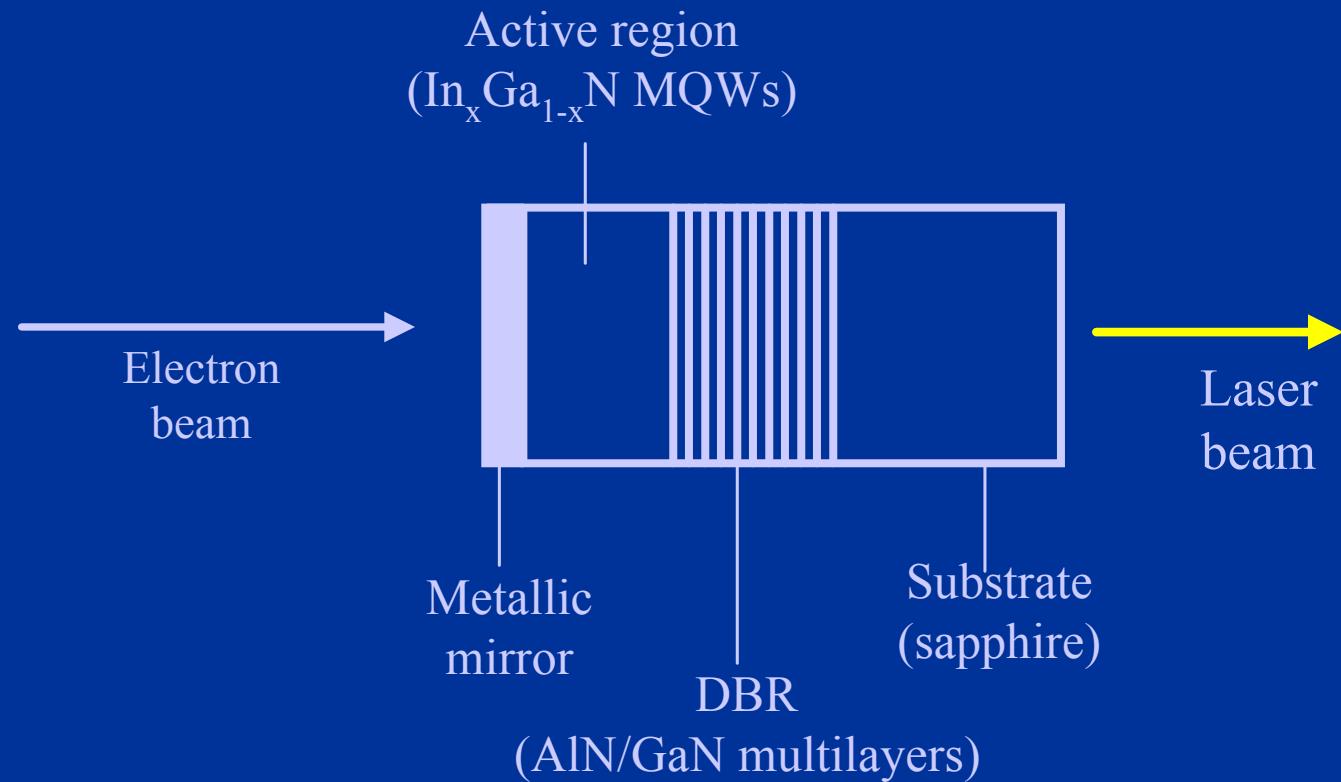
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Outline

- AlN\GaN distributed bragg reflectors grown by MBE
- Growth and properties of InGaN multi-quantum wells
- Preliminary results on a electron beam pumped prototype VCSEL structure
- Ordering in AlGaN Alloys

Schematic of an electron beam pumped NitrideVCSEL Structure



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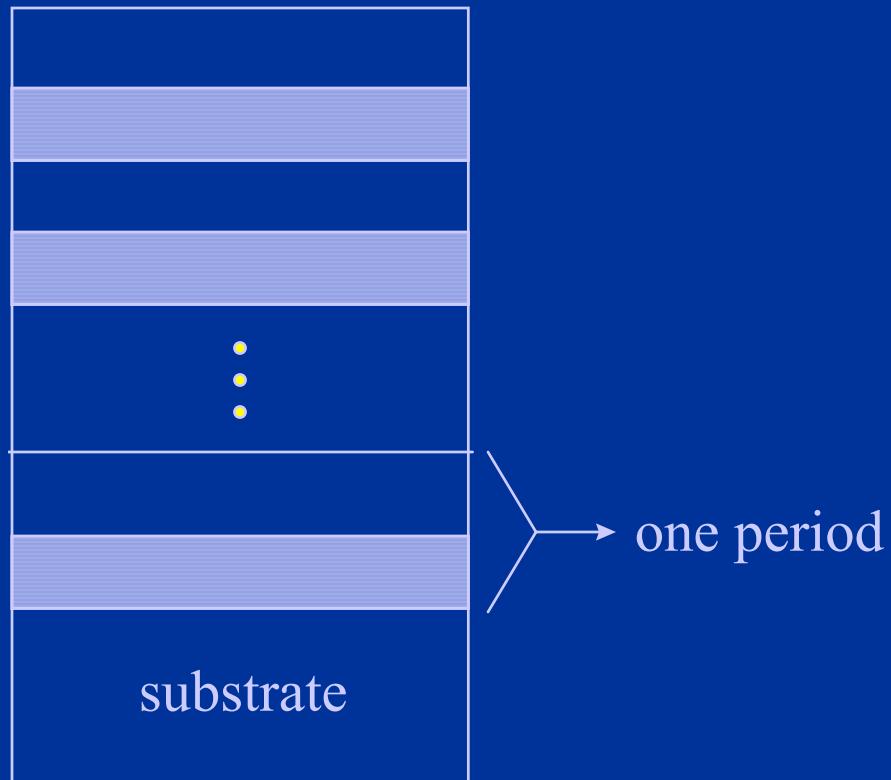
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Schematic of a GaN/AlN DBR

$$n_{GaN}(392 \text{ nm}) = 2.56$$
$$n_{AlN} = 2.26^*$$

Fractional contrast
11.8%

GaN →
AlN →



*J. Pastrnak and L. Roskovcova, *Phys. Stat. Solidi* **14**, pp.K5-K8 (1966)

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Transmission matrix method

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{bmatrix} \cos(\delta_b) & \frac{i \cdot \sin(\delta_b)}{n_1} \\ i \cdot n_b \sin(\delta_b) & \cos(\delta_b) \end{bmatrix} \begin{bmatrix} \cos(\delta_a) & \frac{i \cdot \sin(\delta_a)}{n_a} \\ i \cdot n_a \sin(\delta_a) & \cos(\delta_a) \end{bmatrix}^M \begin{bmatrix} 1 \\ n_{subs} \end{bmatrix}$$

n : refractive index of the corresponding layer

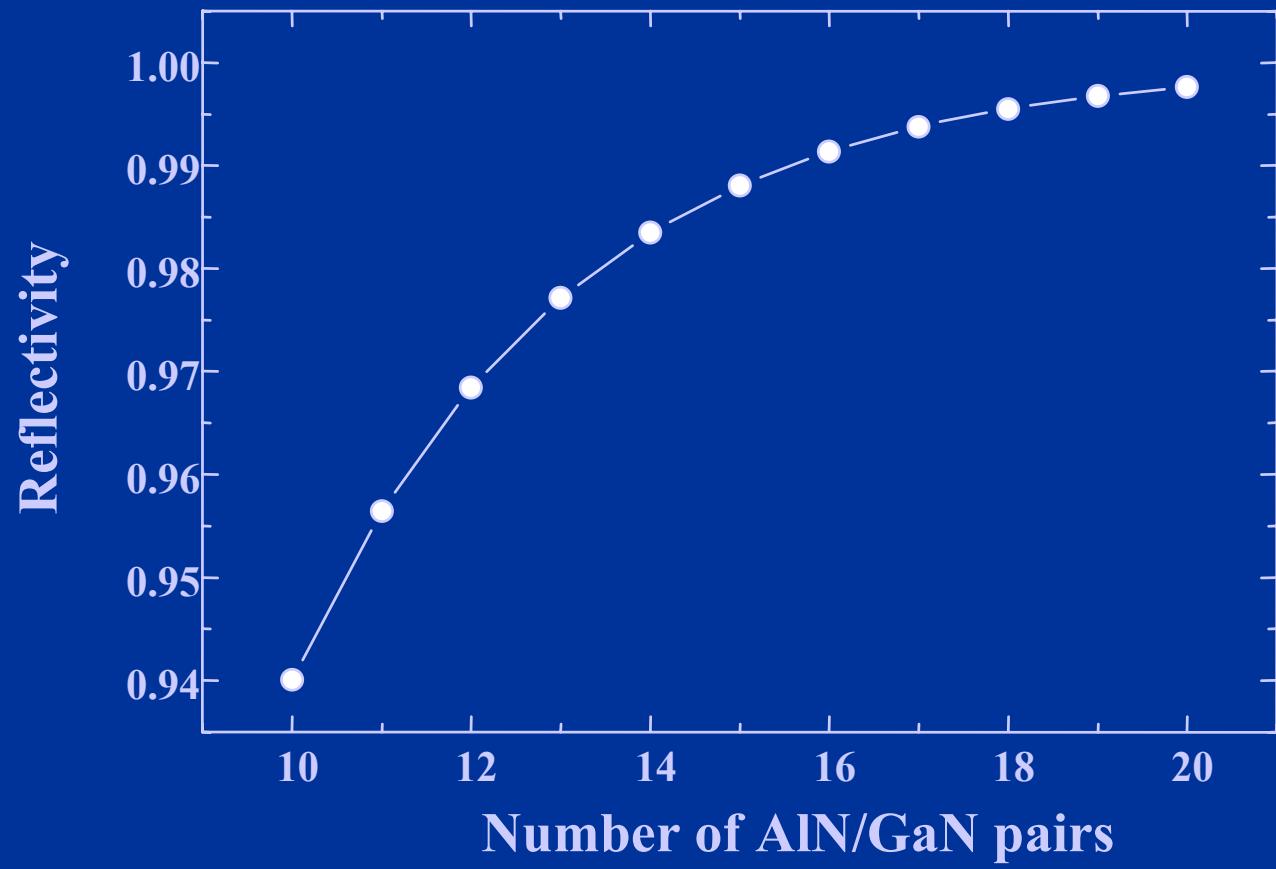
$$\delta_{a,b} = 2\pi n_{a,b} \frac{d_{a,b}}{\lambda}$$

d : geometrical thickness of the corresponding layer

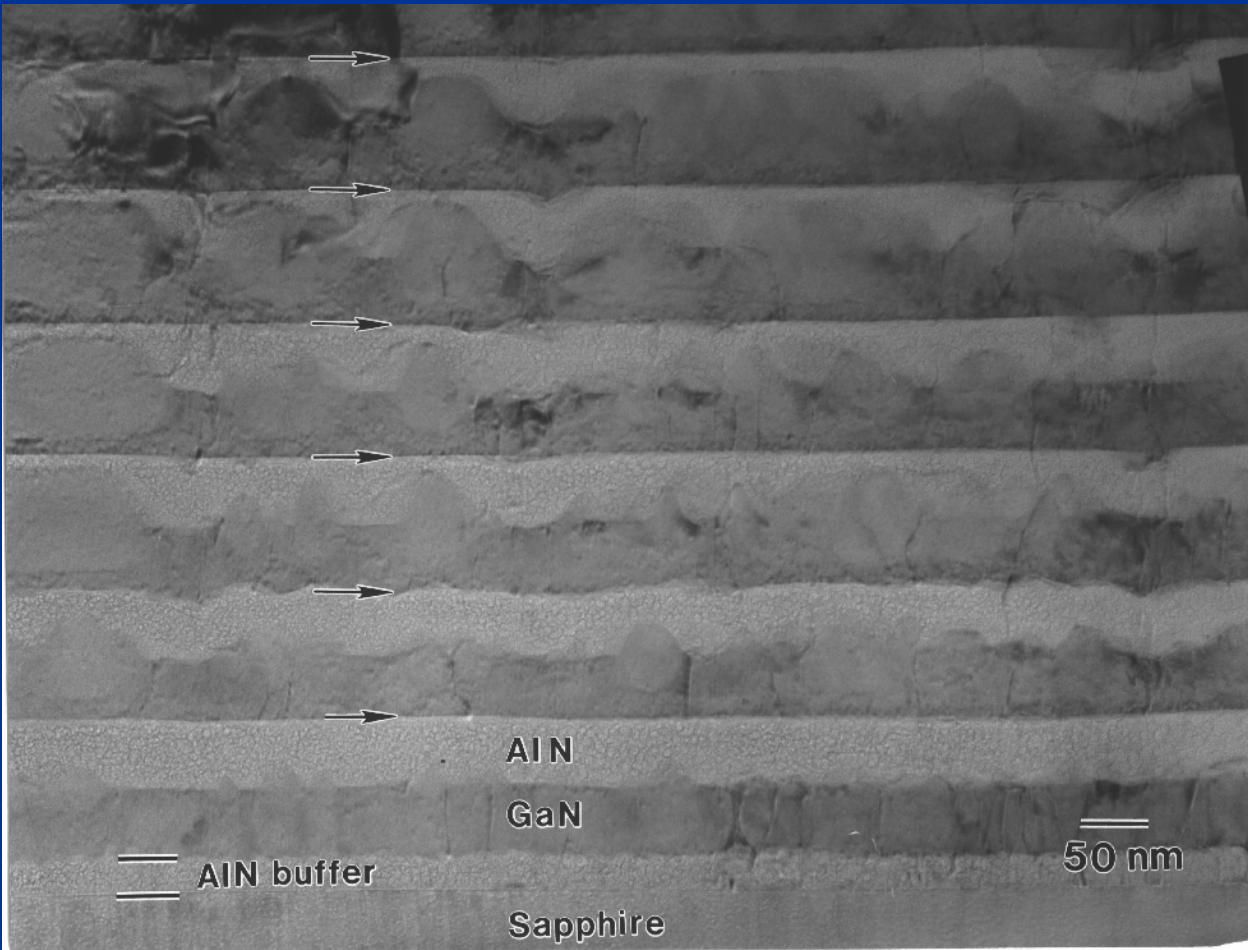
Admittance, $Y = \frac{C}{B}$

Reflectance, $R = \left(\frac{n_0 - Y}{n_0 + Y} \right) \overline{\left(\frac{n_0 - Y}{n_0 + Y} \right)}$

Calculated reflectivity of a DBR stack with variable number of AlN/GaN pairs



Study of the microstructure by TEM



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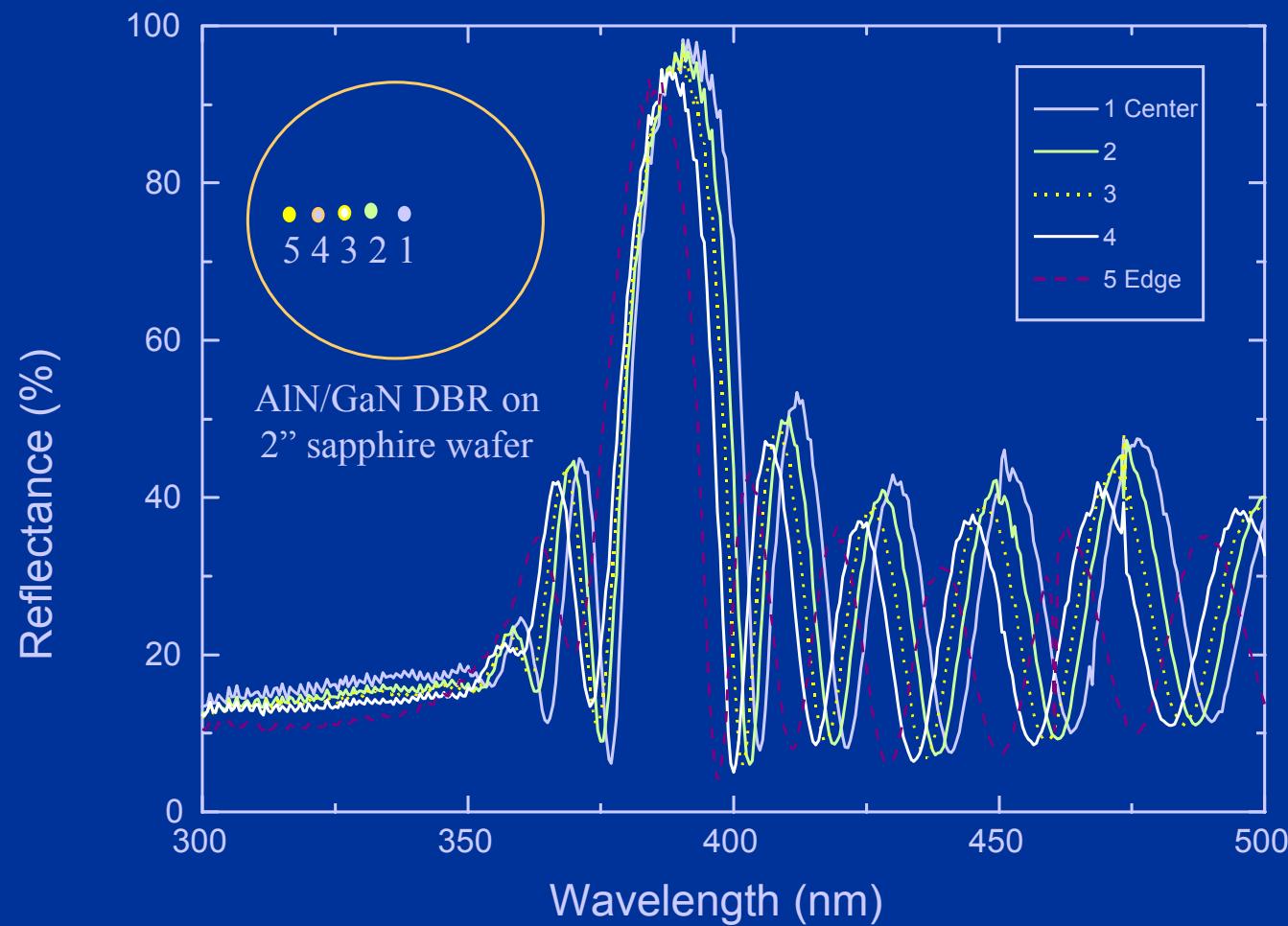
Different growth modes

- AlN on GaN grows in a 2-D mode (Frank-van der Merwe mode)¹
- GaN on AlN grows initially in 2-D mode and becomes 3-D after a few monolayers (Stranski-Krastanov mode)¹
- 2.5% lattice mismatch between AlN ($a=3.112\text{\AA}$) and GaN ($a = 3.189 \text{ \AA}$)
- Thermal expansion coefficients - GaN($5.59\times10^{-6}/\text{K}$), AlN ($4.2\times10^{-6}/\text{K}$), sapphire ($7.5\times10^{-6}/\text{K}$)
- Potential application for GaN quantum dots²

¹ G. Feuillet et al., Proceedings of the 2nd International Conference for Nitride Semiconductors, Tokushima, Japan, p. 498 (1997).

² F. Widmann et al., J. Appl. Phys. **83**, 7618 (1998).

Uniformity across a 2" wafer

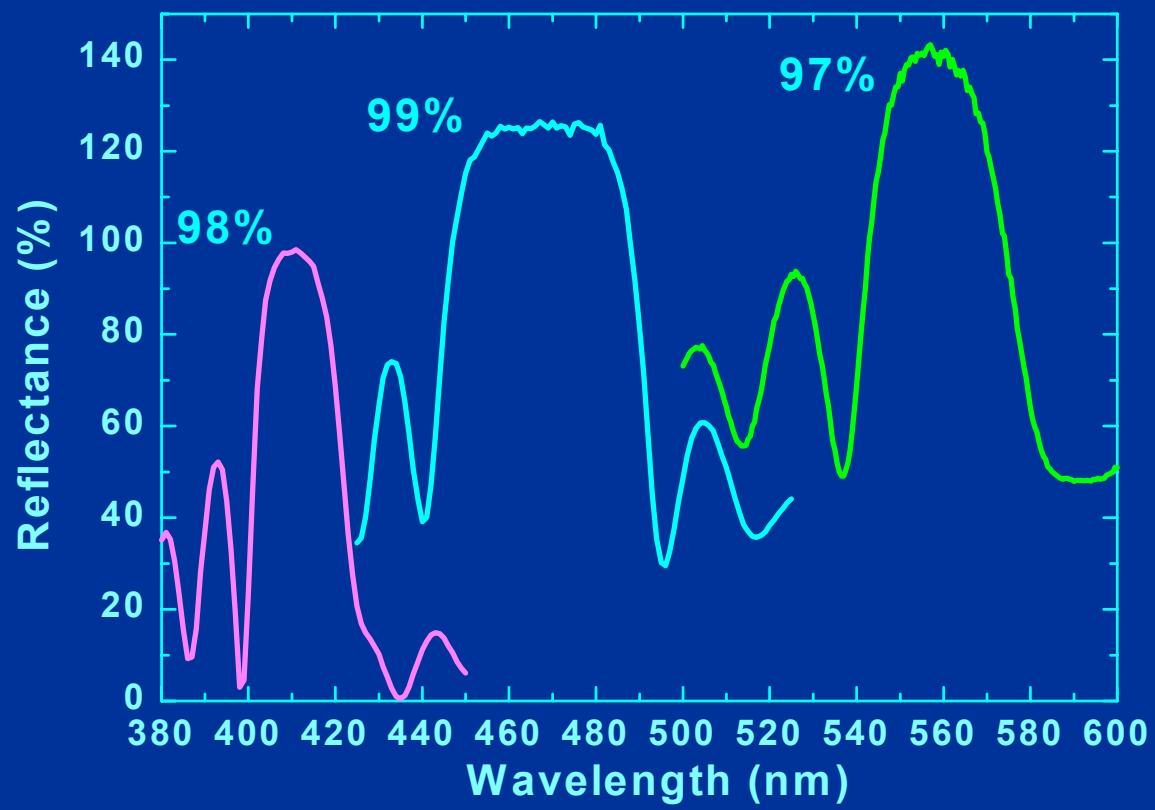


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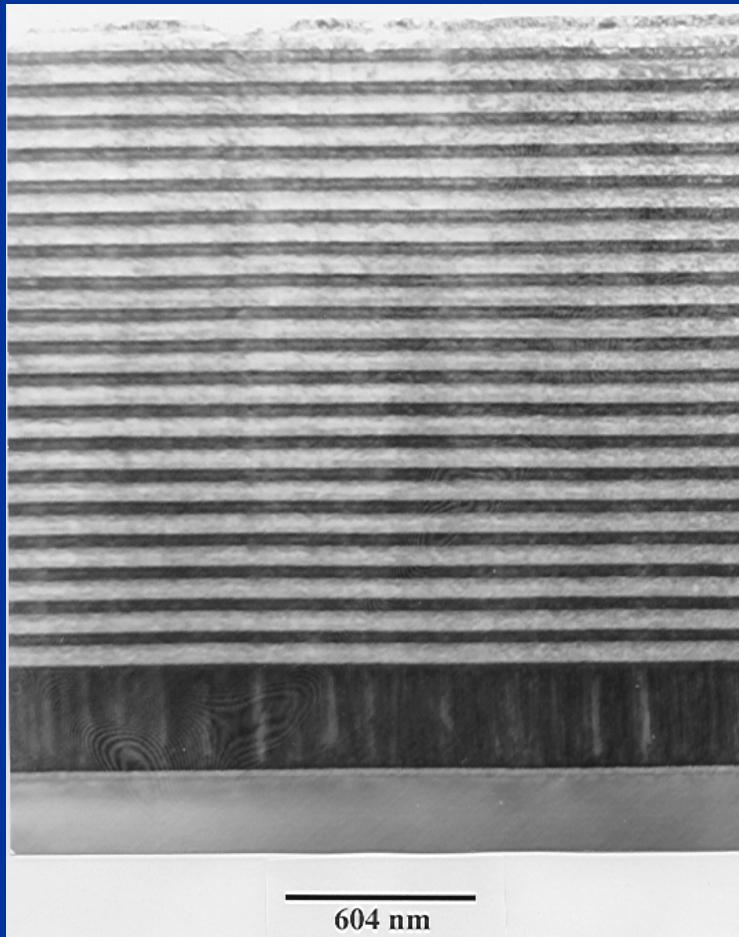
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Distributed Bragg reflectors with high reflectance from violet to green



Cross-section TEM of an AlN/GaN DBR

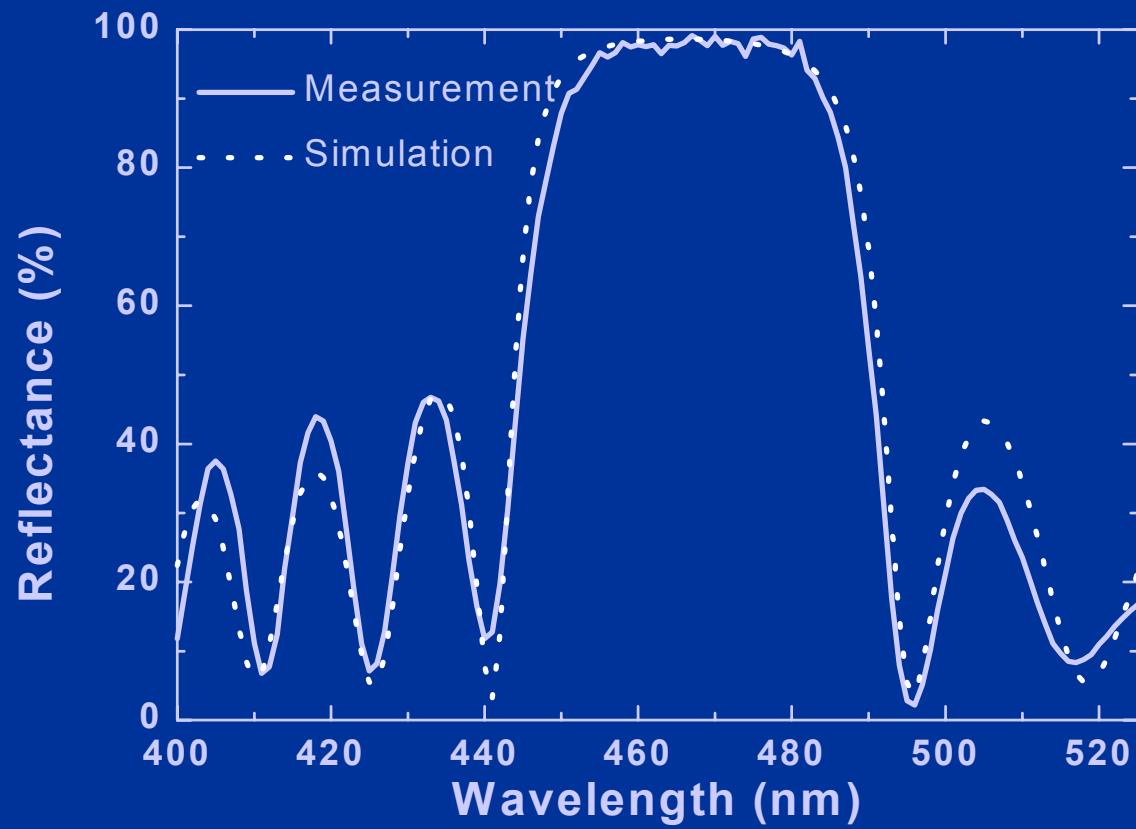


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Optimized DBR structure

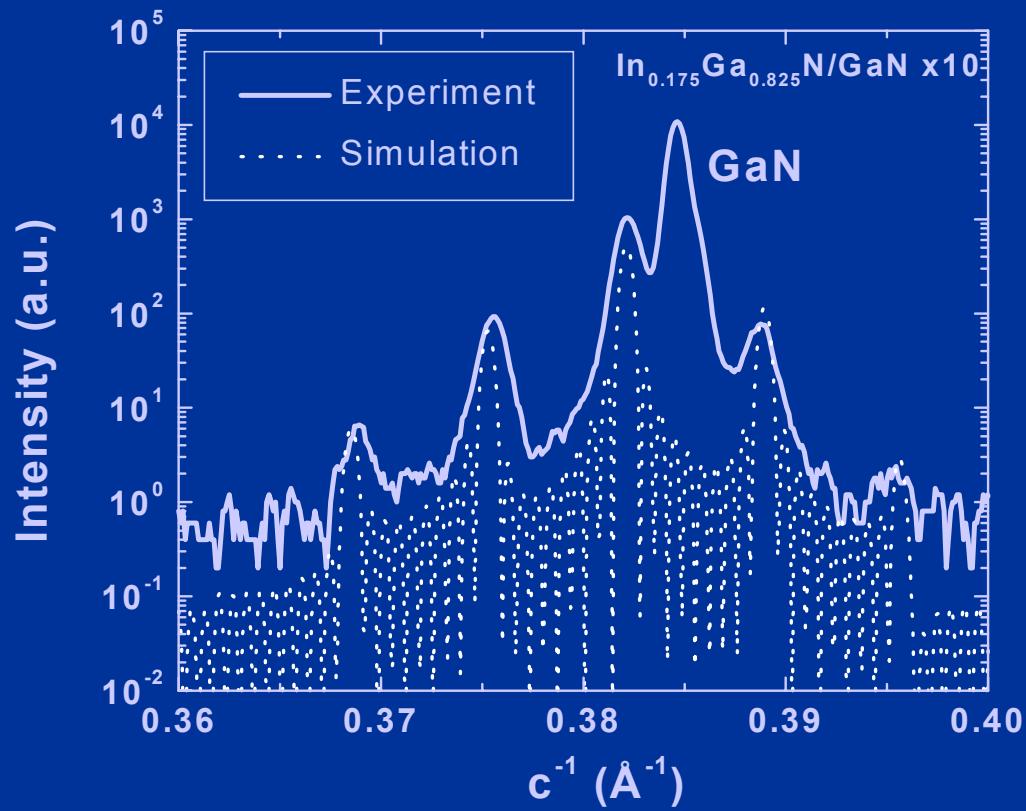


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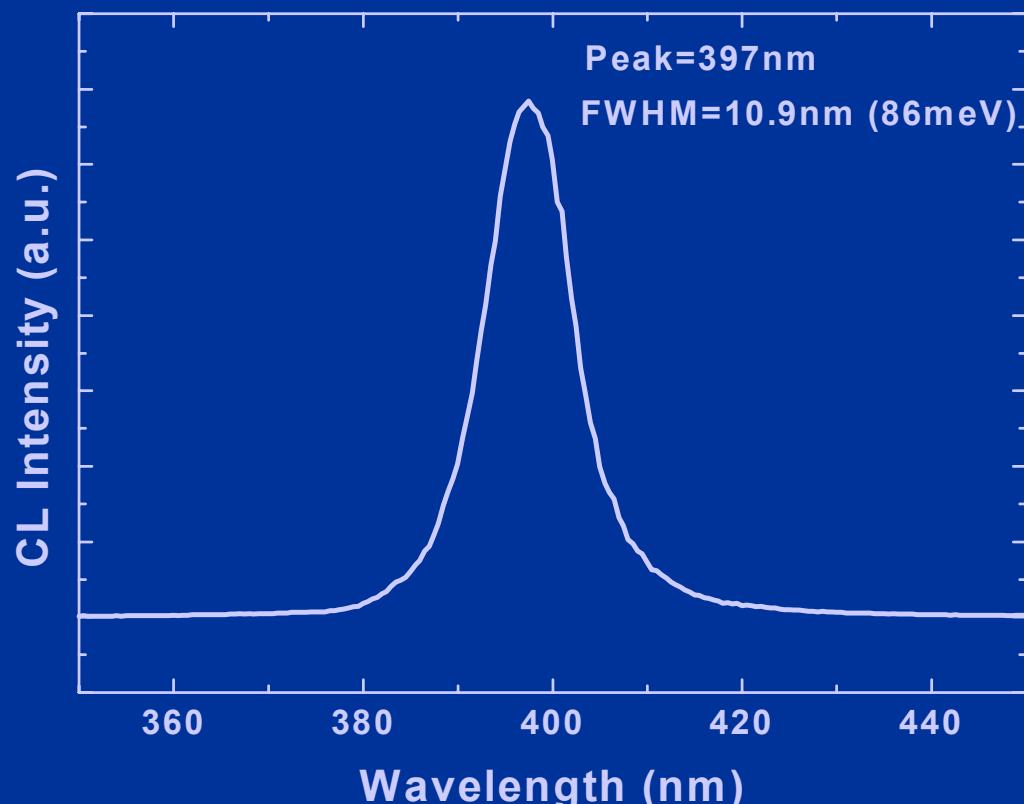
Structural studies of InGaN/GaN MQWs by x-ray diffraction



$$P = \frac{\lambda}{2(\sin \theta_{n+1} - \sin \theta_n)}$$

- P = 15nm
- InGaN wells
7.5nm
- GaN barriers
7.5nm

CL spectrum of the InGaN/GaN MQWs at 300K

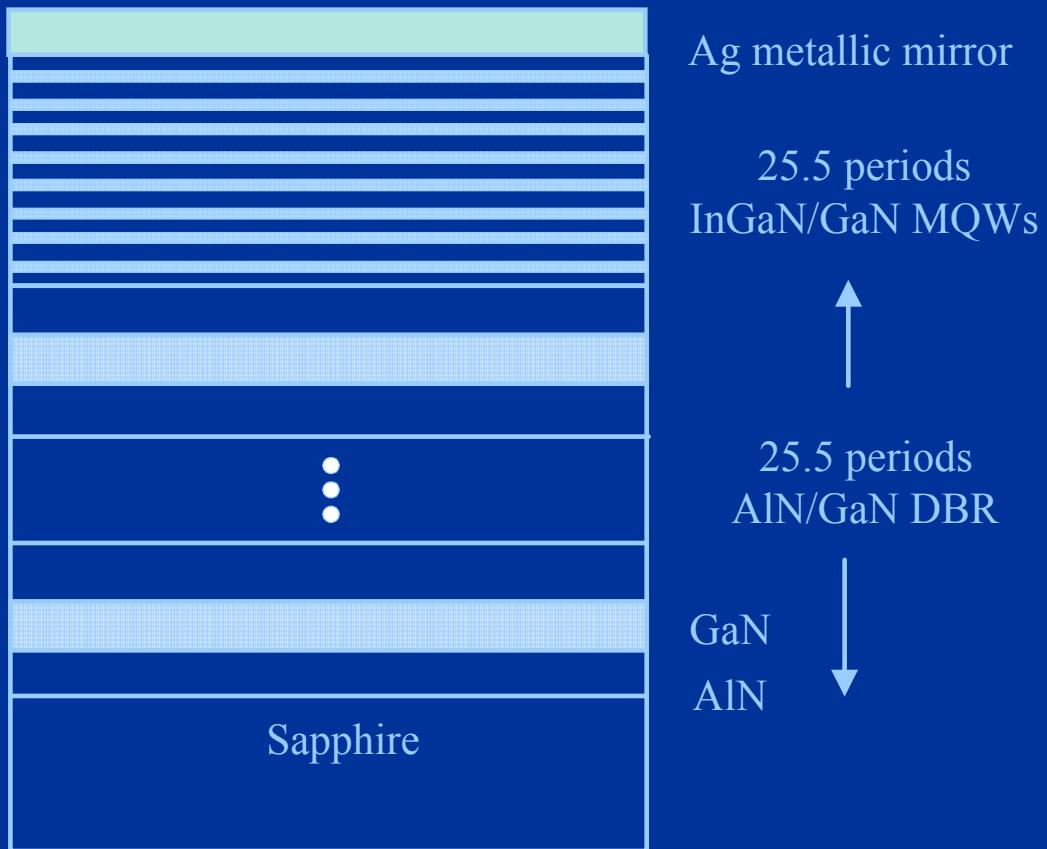


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Schematic of the vertical cavity laser

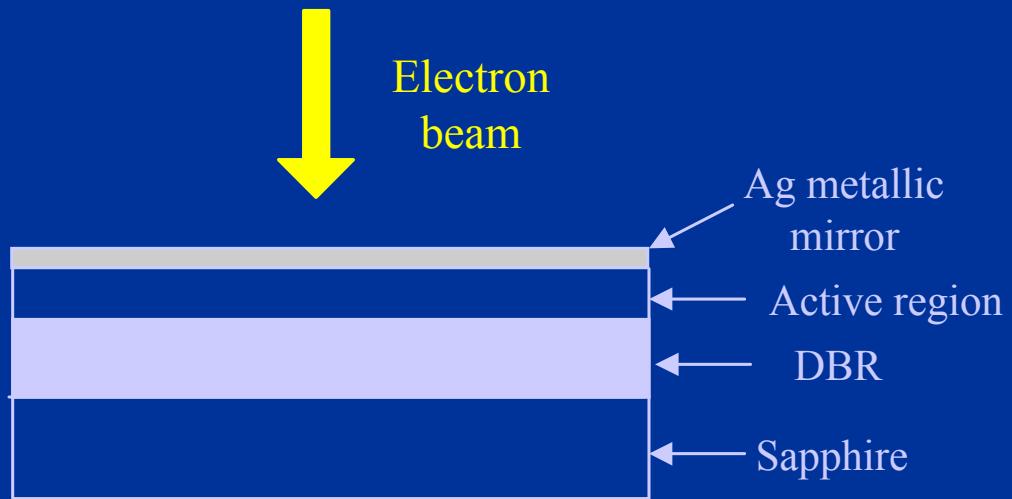


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Electron beam pumping configuration

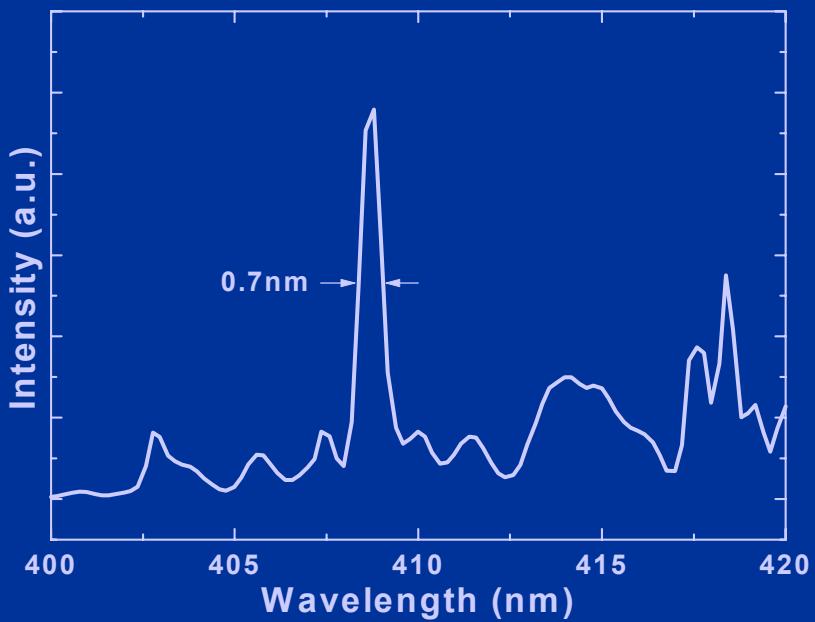
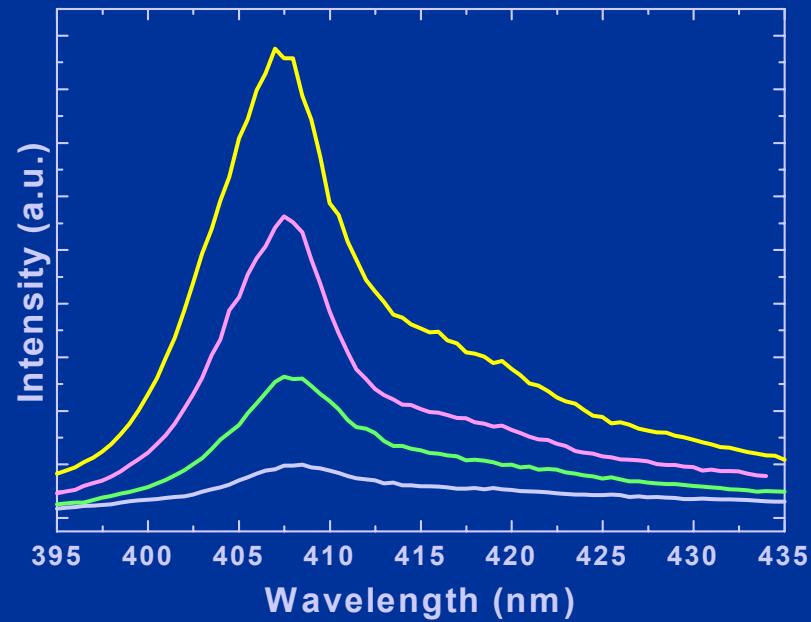


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Stimulated emission at 100K



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Conclusions on VCSELs

Nitride DBRs

- DBRs with peak reflectance ranging from 390-570nm (near-UV to green)
- Highest reflectance achieved was greater than 99% with 45 nm bandwidth

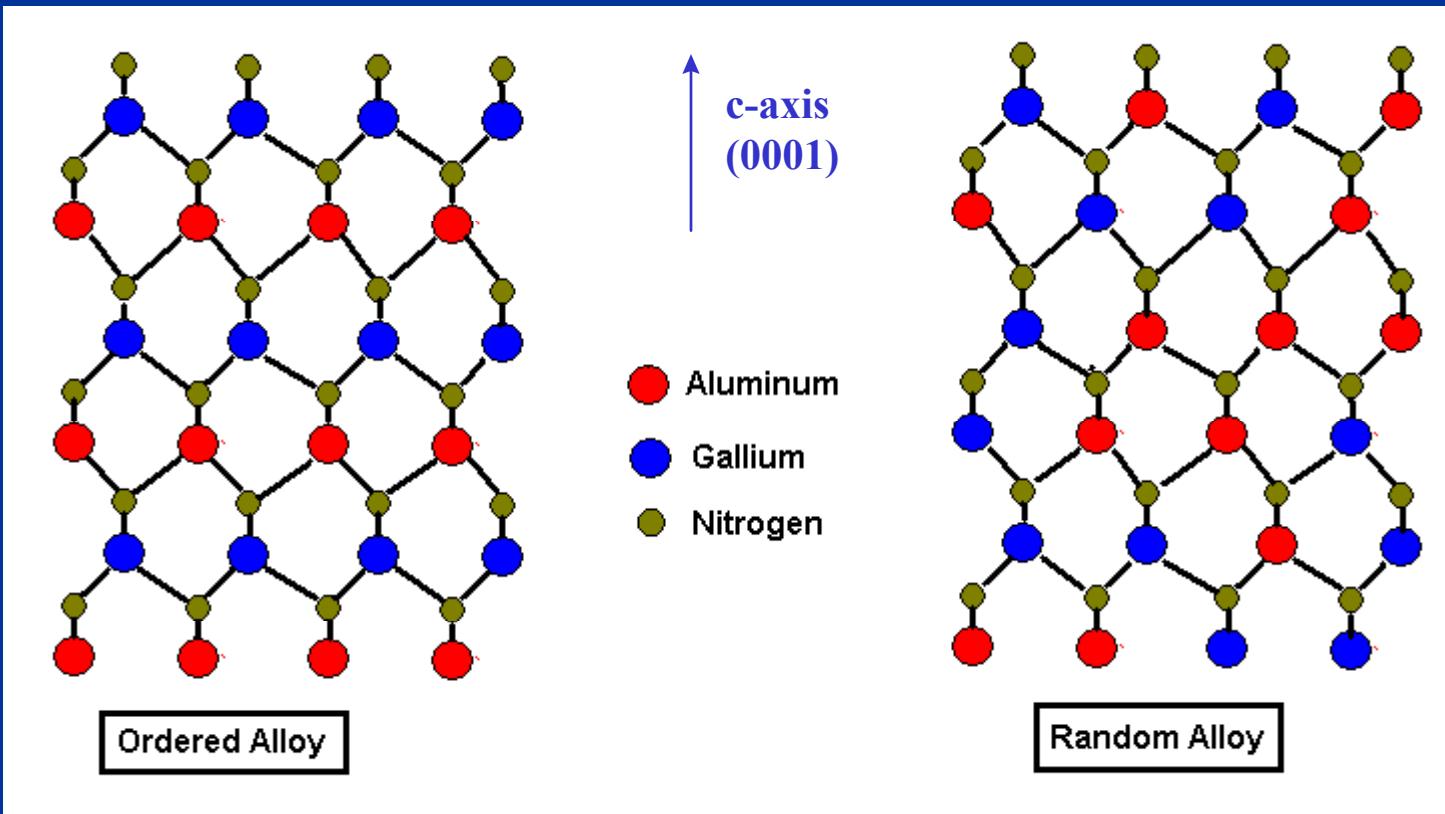
InGaN/GaN MQWs

- XRD studies indicate that the MQWs have sharp interfaces
- CL at 300 K shows a single peak with a FWHM of 11nm

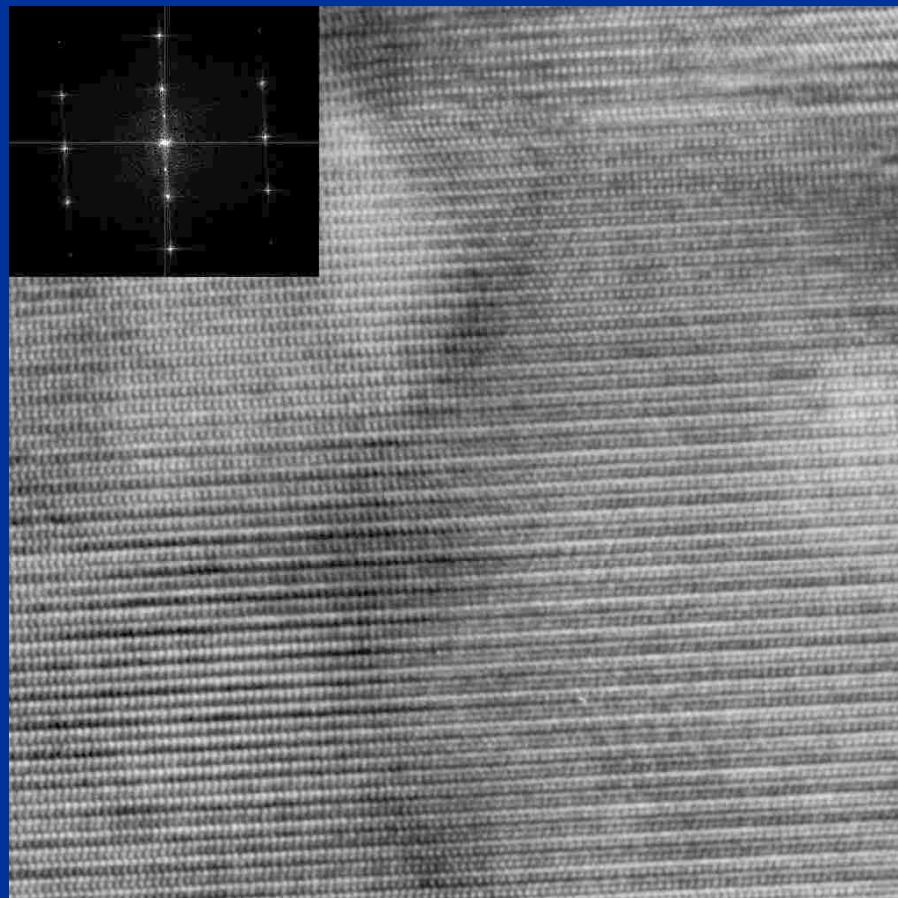
Vertical cavity laser

- Fabricated laser structure consisting of DBRs, InGaN MQW active layer and silver mirror
- Linewidth narrowing and stimulated emission observed at 100K with increased e-beam pumping. (FWHM of 0.7nm at 407nm)

Definition of 1 monolayer superlattice ordering



HR-TEM of (1x1) Ordered structure in AlGaN

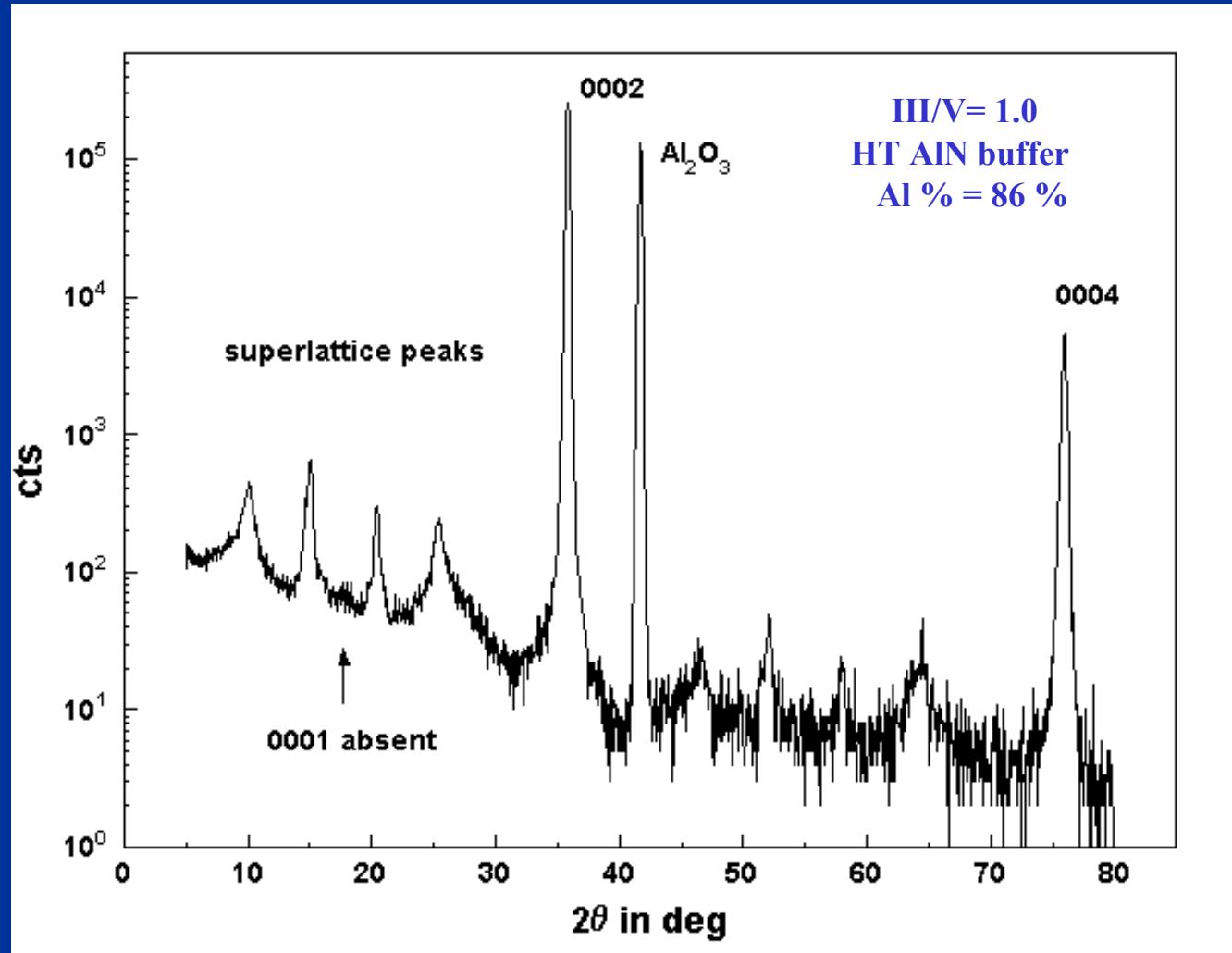


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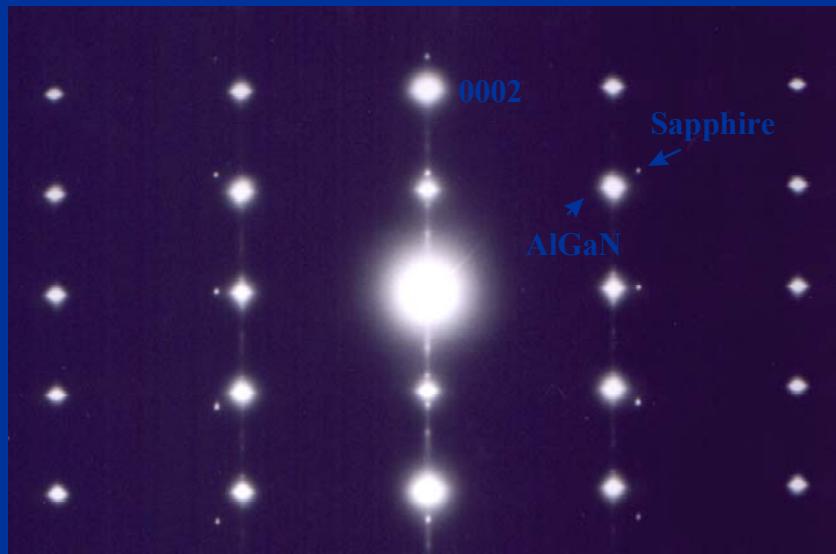
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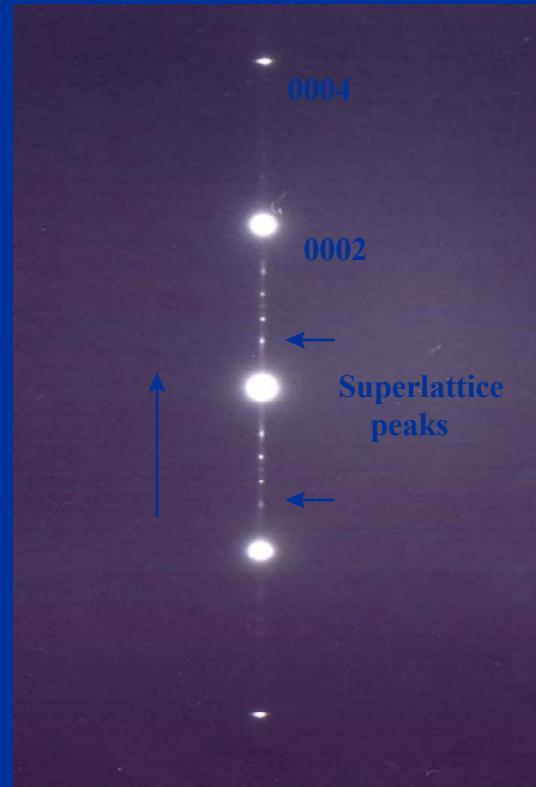
Theta -2 Theta scan of AlGaN film showing superlattice peaks



SAD investigation of AlGaN film

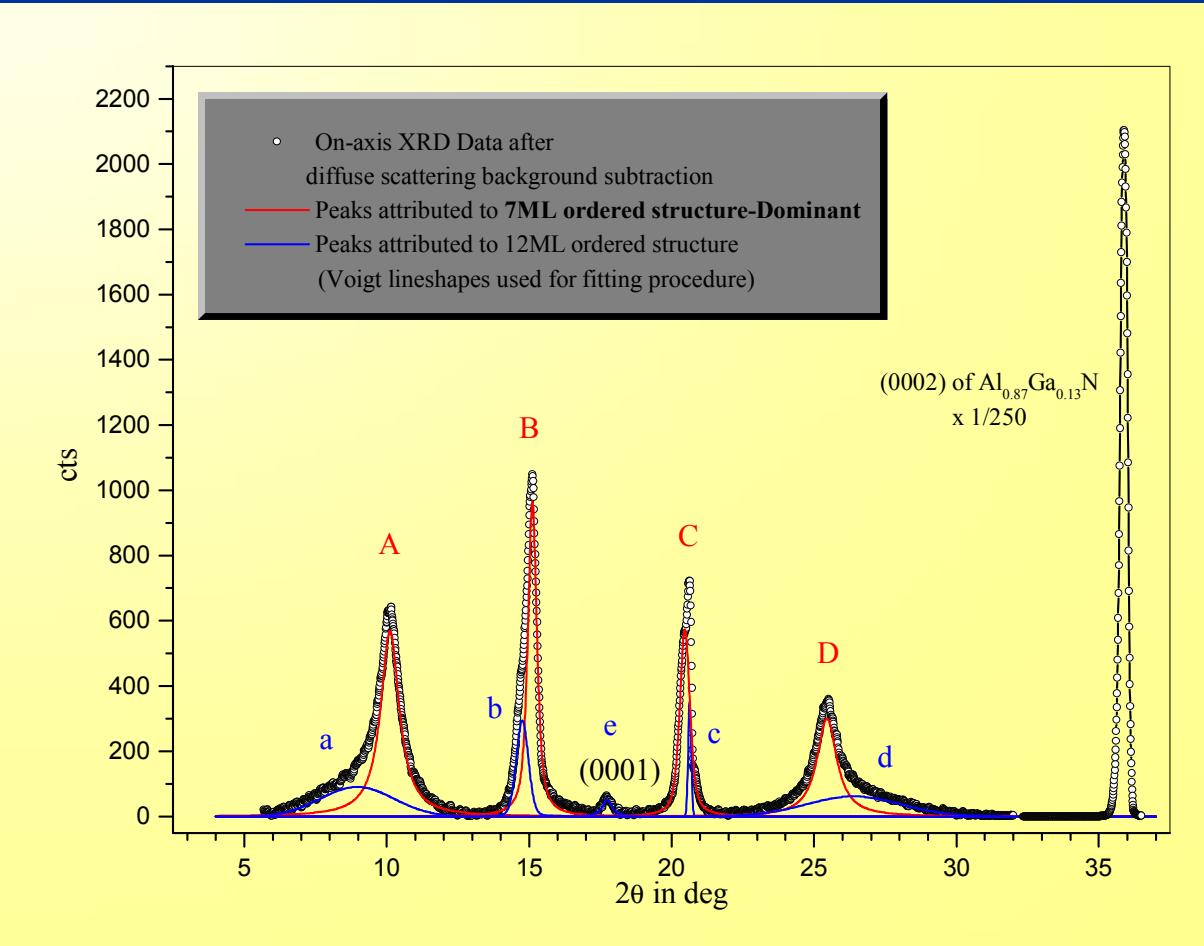


Epi+sub. SAD $<\bar{2}\bar{1}\bar{1}0>$ zone

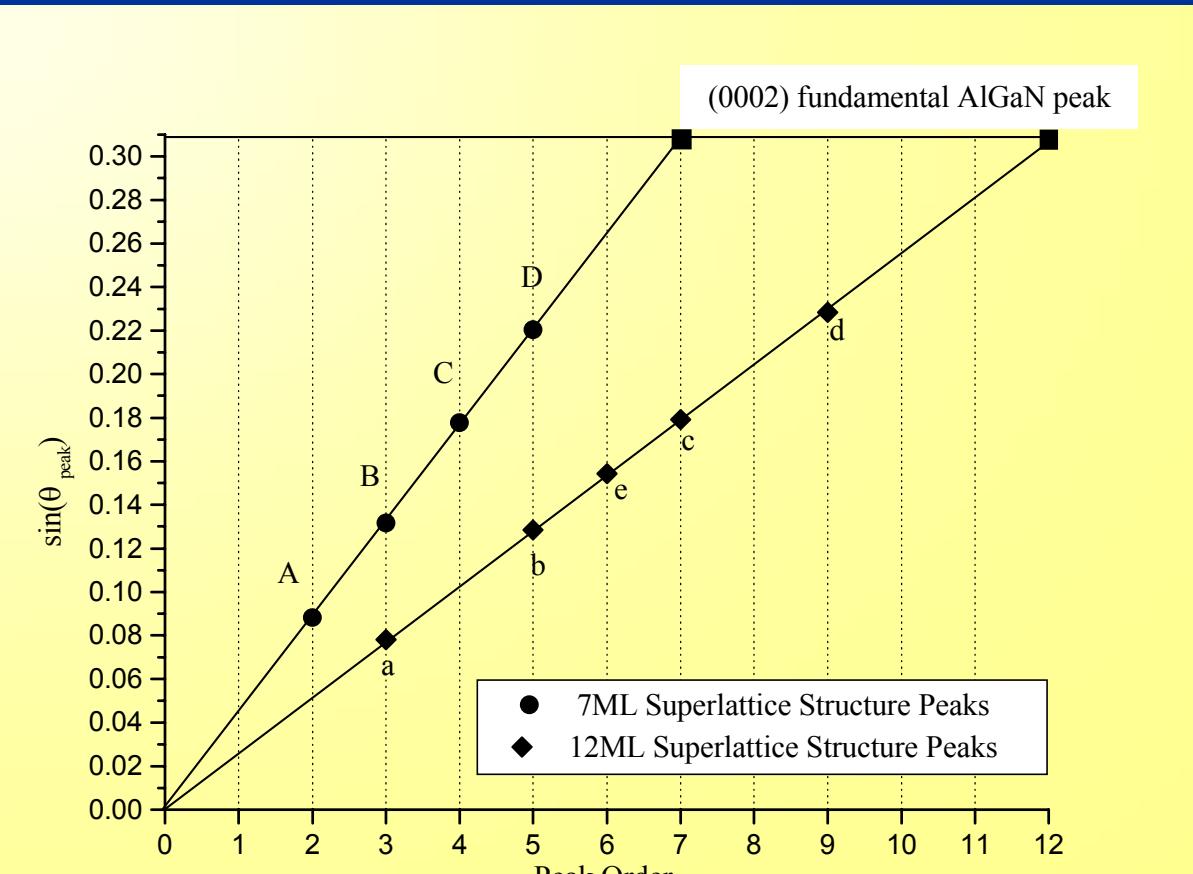


Epi SAD
 $<\bar{2}\bar{1}\bar{1}0>$ zone tilted in $[0\bar{1}\bar{1}0]$ direction

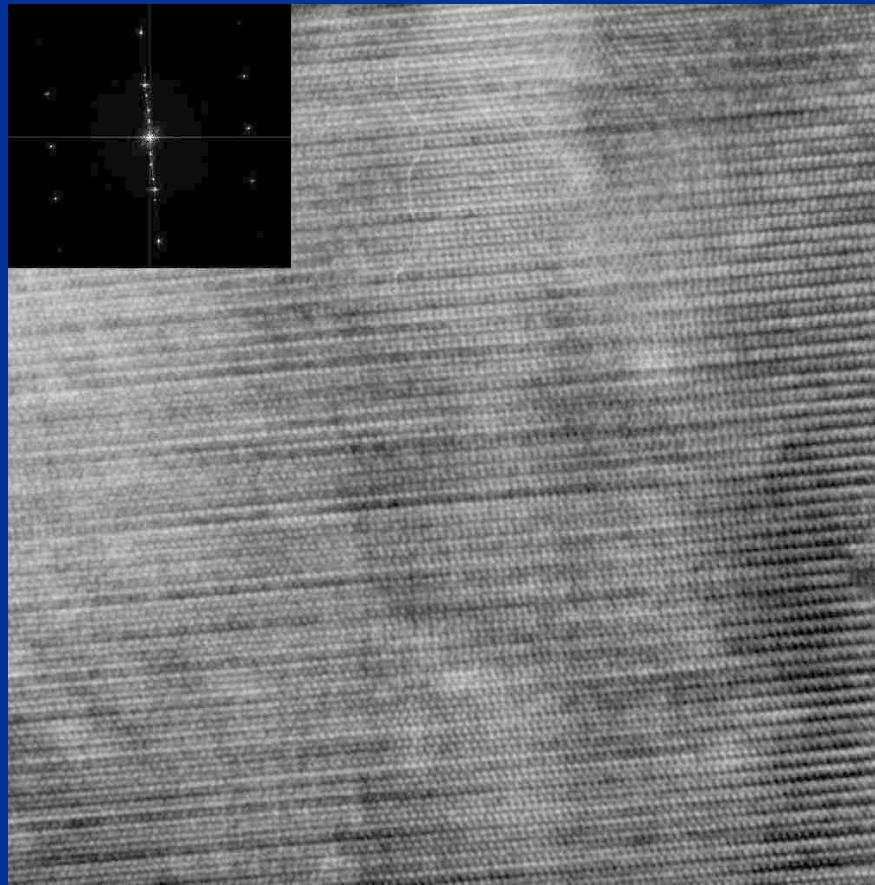
On-axis XRD scan analysis



Analysis of SL structure period



HR-TEM evidence of 7ML ordered structure

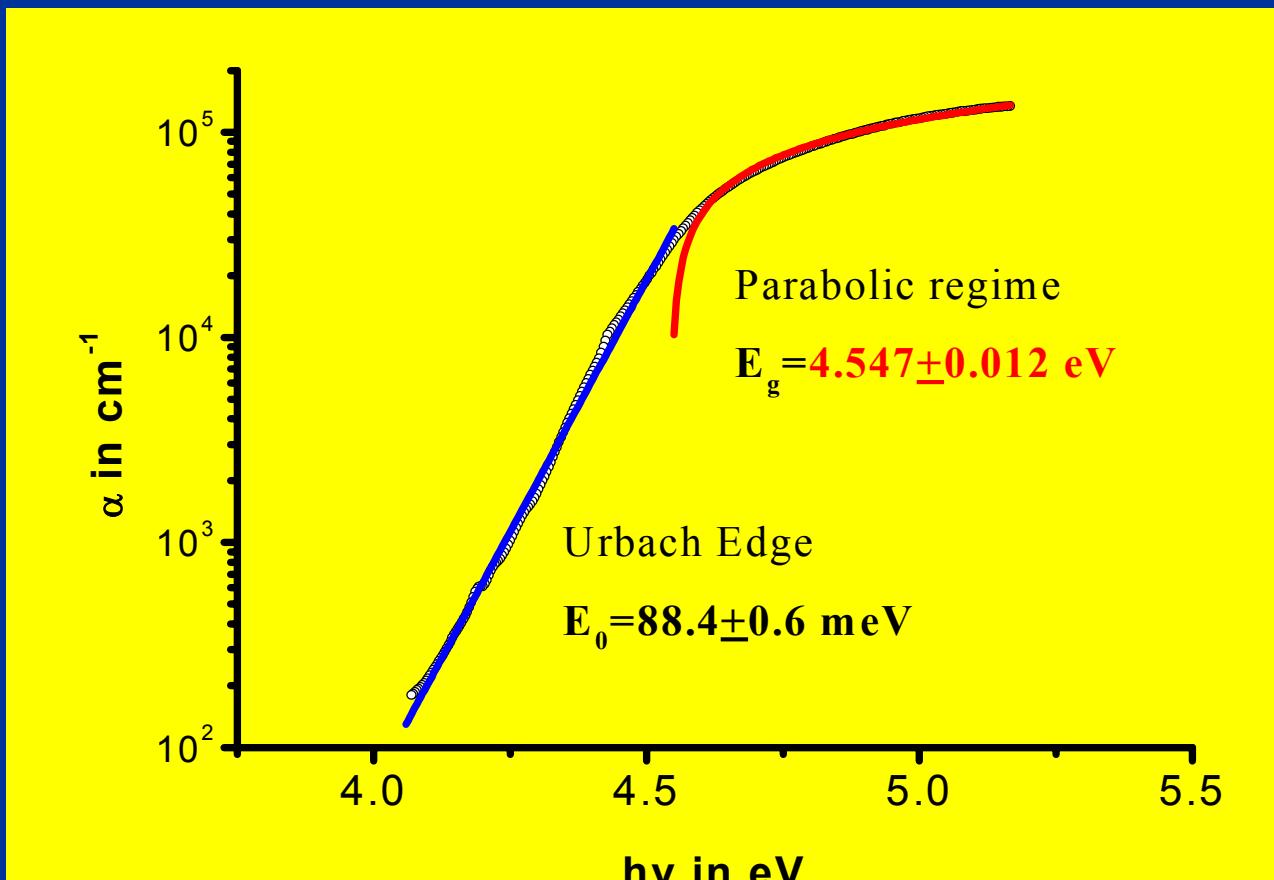


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Absorption spectrum of 1x1 ordered AlGaN film



Conclusions on Ordering in AlGaN Alloys

- Two types of ordering have been observed in AlGaN alloys
 - Films grown under N-rich conditions show 1x1 superlattice structure.
 - Films grown under Group-III rich conditions show a 7 monolayer and a 12 monolayer superlattice structure
- Ordering improves the optical properties of the films.
 - The Urbach Edge of the ordered alloys is sharper than that of random alloys.

